

# Johnson-Cousins magnitudes of comparison stars in the fields of ten Seyfert galaxies\*

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We present  $UBVR_CI_C$  magnitudes of 49 comparison stars in the fields of the Seyfert galaxies Mrk 335, Mrk 79, Mrk 279, Mrk 506, 3C 382, 3C 390.3, NGC 6814, Mrk 304, Ark 564, and NGC 7469 in order to facilitate the photometric monitoring of these objects; 36 of the stars have not been calibrated before. The comparison stars are situated in  $5 \times 5$  arcmin fields centred on the Seyfert galaxies, their  $V$  band flux ranges from 11.7 to 18.2 mag with a median value of 16.3 mag, and their  $B - V$  colour index ranges from 0.4 to 1.6 mag with a median value of 0.8 mag. The median errors of the calibrated  $UBVR_CI_C$  magnitudes are 0.08, 0.04, 0.03, 0.04, and 0.06 mag, respectively. Comparison stars were calibrated for the first time in three of the fields (Mrk 506, 3C 382, and Mrk 304). The comparison sequences in the other fields were improved in various aspects. Extra stars were calibrated in four fields (Mrk 335, Mrk 79, NGC 6814, and NGC 7469) – most of these stars are fainter and are situated closer to the Seyfert galaxies compared to the existing comparison stars. The passband coverage of the sequences in five fields (Mrk 335, Mrk 79, Mrk 279, NGC 6814, and Ark 564) was complemented with  $U$  band.

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## 1 Introduction

Variability is a common property of Active Galactic Nuclei (AGNs). Monitoring programmes undertaken till now provided a lot of information about variability characteristics of AGNs that was successfully used in studying the nuclear activity of galaxies (e.g. Schramm et al. 1993; Dietrich et al. 1998; Shemmer et al. 2001; Bachev & Strigachev 2004; Bachev, Strigachev & Semkov 2005; Villata et al. 2006).

Calibration of optical monitoring light curves is important as AGN monitoring programmes typically combine data from different observatories – to get dense temporal coverage of the resulting light curves over a certain period of time – and from different frequency domains – to study the AGN emission across the electromagnetic spectrum. The preferable photometric technique used to calibrate AGN light curves is relative photometry against local comparison stars. Compared to multi-airmass calibration, it is less time-consuming and makes possible the use of non-photometric nights, too. Therefore, the presence of comparison sequences in the fields of target AGNs is of importance for monitoring programmes. Aside from photometric monitoring of AGNs, the comparison sequences could also be used for surface photometry calibration of the corresponding active galaxies.

Johnson-Cousins comparison sequences in the fields of Seyfert galaxies were presented in the papers of Penston,

Penston & Sandage (1971), Miller (1981,1986), Hamuy & Maza (1989), Curry et al. (1998), Bachev, Strigachev & Dimitrov (2000), González-Pérez, Kidger & Martín-Luis (2001), and Doroshenko et al. (2005a, 2005b). Further improvement of the existing standard sequences along with establishing new ones is highly recommended. The improvement of a comparison star sequence could comprise:

- Addition of new comparison stars in order to extend the magnitude and the colour index ranges covered by the comparison sequence and/or to optimize the distribution of the standards in the field of the target object. The larger number of comparison stars would also increase the accuracy of the zero-point magnitude derived by them;
- Addition of new flux measurements for the existing comparison stars in order to increase the accuracy of their magnitudes. Further check of the comparison stars for variability could also be done;
- Extension of the passband coverage of the calibrated magnitudes.

Since 1997  $UBVR_CI_C$  observations of a number of Seyfert galaxies have been obtained in the course of active galaxy surface photometry programme at the Rozhen National Astronomical Observatory (NAO), Bulgaria, by the authors; about a dozen of the objects have been observed two or more times. We were not able to do a multi-airmass calibration of the data taken during a few of the observing nights due to weather or technical problems. A part of these non-calibrated data was transformed to the standard Johnson-Cousins system using comparison sequences

\* Based on observations obtained with the 2-m telescope of the Rozhen National Astronomical Observatory, which is operated by the Institute of Astronomy, Bulgarian Academy of Sciences.

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**Table 1** A list of the selected Seyfert galaxies. Equatorial coordinates, other names, redshifts, and Seyfert types of activity were taken from NASA/IPAC Extragalactic Database (NED). The number of the different observing nights,  $N$ , at which the data were taken is specified in the last column; the  $U$  band data of Mrk 335, Mrk 79, Mrk 506, NGC 6814, and Mrk 304 were taken at a single epoch. The superscript  $n$  means the number of nights used in the internal check for variability of the newly calibrated stars (see Sect. 4); the missing superscript means no new comparison stars were added to the corresponding fields.

Galaxy	Other names	RA (J2000)	Dec (J2000)	$z$	Sy	$N^n$
Mrk 335		00:06:19.521	20:12:10.49	0.02578	1.2	2 <sup>3</sup>
Mrk 79	UGC 03973, CGCG 235 – 030, MCG + 08 – 14 – 033	07:42:32.797	49:48:34.75	0.02219	1.2	2 <sup>3</sup>
Mrk 279	UGC 08823, CGCG 336 – 028, MCG + 12 – 13 – 022	13:53:03.447	69:18:29.57	0.03045	1.5	1
Mrk 506	CGCG 170 – 020, MCG + 05 – 41 – 012	17:22:39.899	30:52:53.01	0.04303	1.5	2 <sup>3</sup>
3C 382	CGCG 173 – 014	18:35:03.391	32:41:46.82	0.05787	1.0	2 <sup>3</sup>
3C 390.3	VII Zw 838	18:42:08.990	79:46:17.13	0.05610	1.0	2
NGC 6814	MCG – 02 – 50 – 001	19:42:40.644	–10:19:24.57	0.00521	1.5	3 <sup>4</sup>
Mrk 304	II Zw 175, CGCG 428 – 065	22:17:12.260	14:14:20.90	0.06576	1.0	2 <sup>4</sup>
Ark 564	UGC 12163, CGCG 495 – 018, MCG + 05 – 53 – 012	22:42:39.345	29:43:31.31	0.02468	1.8	2
NGC 7469	UGC 12332, CGCG 405 – 026, MCG + 01 – 58 – 025	23:03:15.623	08:52:26.39	0.01632	1.2	2 <sup>4</sup>

established in the corresponding object fields, whereas for the rest this approach failed because of the following reasons: (1) the comparison stars lay outside our field of view, (2) the standards were saturated in our frames, (3) the standard sequence did not cover some of the photometric bands (usually  $U$ ), and (4) there was no comparison sequence established in the field. A possible approach in these cases is matching the non-calibrated host galaxy profiles or galaxy multi-aperture magnitudes to calibrated ones (e.g. Kotilainen, Ward & Williger 1993). However, this type of calibration is of lower accuracy compared to both multi-airmass and relative calibration.

In order to transform the non-calibrated data of ours to the standard system and to facilitate future AGN monitoring, we re-examined our observational data with the purpose to find objects suitable (1) for establishing new comparison sequences in their fields and (2) for improving the standard sequences already existing. A total of ten Seyfert galaxies were selected as a result of this search; some information about these objects is listed in Table 1. We present the results of the  $UBVR_CI_C$  calibration of comparison stars in the fields of the selected galaxies in this paper.

The paper is organized as follows. The observations and data reduction are presented in Sect. 2. The flux measurement and magnitude calibration are described in Sect. 3. The general characteristics of the calibrated stars are discussed in Sect. 4. Comments on the individual fields are presented in Sect. 5 and we summarize the main results of this paper in Sect. 6.

## 2 Observations and data reduction

All observations were done by the authors using the 2-m telescope of NAO during the period 1997 – 2003. A liquid nitrogen cooled  $1024 \times 1024$  Photometrics AT200 model CCD camera (CCD chip SITE SI003AB having  $24 \mu\text{m}$  square

pixel) was attached to the Ritchie-Chrétien focus of the telescope giving a scale factor of  $0.309 \text{ arcsec px}^{-1}$  and a square, 5.3 arcmin wide field of view. A standard Johnson-Cousins  $UBVR_CI_C$  set of filters was used. Multiple exposures of each object field were taken as a rule. Zero exposure frames were taken regularly each observing run and flat fields were taken during evening and/or morning twilights; dark current was negligible as the CCD chip was cooled down to  $-100$  degrees of Celsius. The typical size of the seeing disk was about 2 arcsec. The binning factor of the CCD camera was changed depending on the seeing conditions – we tried to ensure about 3 pixels per FWHM in order to maximize the signal-to-noise ratio without loss of resolution. Standard sequences established in stellar clusters were observed two or three times each night in order to determine the transformation coefficients to the standard Johnson-Cousins system. We used the clusters Messier 67 (Chevalier & Ilovaisky 1991), Messier 92 (Majewski et al. 1994), and NGC 7790 (Odewahn, Bryja & Humphreys 1992; Petrov et al. 2001) for this purpose. Note that we have added 0.002 mag to the  $V$  magnitudes and to the  $B - V$  colour indices of the Messier 92 standard stars listed in Majewski et al. (1994) according to the addendum of Stetson & Harris (1988). The cluster standards were observed at airmass values between 1 and 2; in each case the programme fields were observed within that range.

The initial processing of the frames was performed using ESO-MIDAS package and following the standard CCD reduction steps. The mean bias level was estimated using properly selected columns of the virtual prescan section of the CCD chip and then subtracted. The removal of the residual bias pattern was done using a median zero exposure frame, and the flat fielding and de-fringing were performed employing median flat field and fringe frames, respectively; de-fringing was applied only to  $I_C$  frames. Cosmic ray hits were cleaned up using FILTER/COSMIC command. The in-

**Table 2** Apparent Johnson-Cousins  $UBVR_CI_C$  magnitudes of the comparison stars, their errors (in parentheses), and the number of the individual estimates used to obtain the final magnitude. We list the other designations of the comparison stars that have been calibrated by other authors as well; the superscripts to these designations refer to the corresponding literature sources. The stars without other designations have been calibrated for the first time by us. Dots mean we have not been able to obtain the corresponding magnitudes (see Sect. 5 for comments).

Star	RA (J2000)	Dec (J2000)	$U$	$B$	$V$	$R_C$	$I_C$
<b>Mrk 335</b>							
<b>A:</b> 1 <sup>b</sup> , B <sup>c</sup> , 4 <sup>e</sup>	00:06:20.107	20:10:50.59	16.17 (0.08) 1	15.42 (0.03) 2	14.25 (0.03) 2	13.70 (0.03) 2	13.12 (0.06) 2
<b>B</b>	00:06:14.808	20:11:34.20	17.31 (0.08) 1	17.38 (0.03) 2	16.85 (0.03) 2	16.55 (0.03) 2	16.22 (0.05) 2
<b>C:</b> 2 <sup>b</sup> , C <sup>c</sup> , 6 <sup>e</sup>	00:06:17.971	20:13:17.60	15.40 (0.08) 1	15.43 (0.03) 2	15.00 (0.03) 2	14.78 (0.03) 2	14.55 (0.06) 2
<b>D</b>	00:06:17.135	20:14:08.72	16.28 (0.09) 1	16.14 (0.04) 2	15.38 (0.03) 2	15.00 (0.04) 2	14.59 (0.06) 2
<b>Mrk 79</b>							
<b>A</b>	07:42:35.026	49:47:01.59	19.18 (0.09) 1	18.84 (0.04) 2	17.94 (0.06) 2	17.48 (0.05) 2	17.05 (0.11) 2
<b>B</b>	07:42:25.704	49:48:07.52	17.62 (0.09) 1	17.60 (0.05) 2	16.88 (0.05) 2	16.53 (0.05) 2	16.13 (0.08) 2
<b>C:</b> 4 <sup>e</sup>	07:42:22.633	49:48:17.49	15.02 (0.10) 1	14.98 (0.06) 1	14.30 (0.05) 1	13.98 (0.06) 1	13.61 (0.07) 1
<b>D</b>	07:42:42.113	49:49:46.54	20.08 (0.09) 1	18.66 (0.04) 2	17.42 (0.06) 2	16.70 (0.07) 2	16.04 (0.07) 2
<b>E</b>	07:42:24.547	49:49:54.38	19.46 (0.09) 1	18.39 (0.08) 2	17.01 (0.04) 2	16.12 (0.08) 2	15.22 (0.06) 2
<b>Mrk 279</b>							
<b>A:</b> D <sup>c,f</sup>	13:53:21.781	69:16:30.34	16.37 (0.06) 1	16.23 (0.05) 1	15.53 (0.03) 1	15.16 (0.05) 1	14.82 (0.08) 1
<b>B:</b> A <sup>c,f</sup>	13:53:21.294	69:18:07.97	14.07 (0.05) 1	13.11 (0.05) 1	12.06 (0.03) 1	...	...
<b>C:</b> C <sup>c,f</sup>	13:52:54.690	69:20:14.75	16.69 (0.07) 1	15.79 (0.05) 1	14.78 (0.03) 1	14.23 (0.06) 1	13.81 (0.09) 1
<b>Mrk 506</b>							
<b>A</b>	17:22:37.829	30:50:10.71	20.01 (0.06) 1	19.13 (0.03) 2	17.72 (0.02) 2	16.90 (0.04) 2	16.03 (0.05) 2
<b>B</b>	17:22:32.619	30:51:23.33	19.02 (0.05) 1	18.23 (0.03) 2	17.12 (0.02) 2	16.49 (0.04) 2	15.87 (0.04) 2
<b>C</b>	17:22:43.293	30:52:00.91	20.65 (0.05) 1	19.49 (0.03) 2	17.92 (0.02) 2	16.86 (0.04) 2	15.45 (0.04) 2
<b>D</b>	17:22:33.955	30:52:02.37	17.85 (0.05) 1	16.62 (0.03) 2	15.33 (0.02) 2	14.59 (0.04) 2	13.92 (0.04) 2
<b>E</b>	17:22:47.853	30:52:12.09	17.86 (0.06) 1	18.03 (0.03) 2	17.46 (0.02) 2	17.14 (0.05) 2	16.80 (0.05) 2
<b>F</b>	17:22:42.842	30:52:59.42	14.92 (0.05) 1	15.05 (0.03) 2	14.61 (0.02) 2	14.38 (0.03) 2	14.13 (0.04) 2
<b>3C 382</b>							
<b>A</b>	18:35:06.547	32:40:02.03	18.32 (0.09) 2	17.46 (0.05) 1	16.42 (0.03) 2	15.82 (0.04) 2	15.37 (0.05) 2
<b>B</b>	18:34:57.385	32:41:17.26	17.37 (0.12) 2	17.00 (0.05) 1	16.27 (0.02) 2	15.86 (0.03) 2	15.57 (0.04) 2
<b>C</b>	18:35:01.184	32:42:43.29	17.86 (0.07) 2	17.99 (0.05) 1	17.41 (0.02) 2	17.03 (0.02) 2	16.77 (0.05) 2
<b>D</b>	18:35:05.136	32:42:44.90	17.72 (0.21) 2	16.80 (0.05) 1	15.76 (0.03) 2	15.18 (0.02) 2	14.75 (0.04) 2
<b>E</b>	18:35:01.718	32:42:58.12	17.34 (0.13) 2	17.16 (0.05) 1	16.51 (0.02) 2	16.10 (0.02) 2	15.80 (0.04) 2
<b>F</b>	18:35:07.086	32:43:27.46	16.30 (0.12) 2	15.83 (0.05) 1	15.00 (0.02) 2	14.52 (0.02) 2	14.16 (0.04) 2
<b>G</b>	18:34:57.009	32:43:33.51	15.95 (0.04) 2	15.99 (0.05) 1	15.55 (0.02) 2	15.15 (0.02) 2	14.87 (0.05) 2
<b>3C 390.3</b>							
<b>A:</b> A <sup>a</sup> , 1 <sup>b</sup>	18:42:23.706	79:45:39.09	13.65 (0.08) 2	12.74 (0.04) 2	11.73 (0.08) 2	11.11 (0.05) 1	10.66 (0.07) 1
<b>B:</b> B <sup>a,f</sup> , 2 <sup>b</sup>	18:42:00.991	79:47:35.25	15.12 (0.05) 2	15.02 (0.04) 2	14.31 (0.03) 2	13.94 (0.06) 2	13.56 (0.05) 2
<b>C:</b> D <sup>a,f</sup> , 3 <sup>b</sup>	18:41:29.706	79:47:59.64	15.72 (0.06) 2	15.45 (0.05) 2	14.66 (0.05) 2	14.29 (0.08) 2	13.92 (0.07) 2
<b>NGC 6814</b>							
<b>A</b>	19:42:34.053	−10:21:03.98	...	19.43 (0.08) 2	17.91 (0.02) 3	17.16 (0.03) 3	16.47 (0.06) 2
<b>B</b>	19:42:32.218	−10:18:55.05	17.75 (0.08) 1	17.28 (0.03) 2	16.31 (0.02) 3	15.84 (0.03) 3	15.40 (0.05) 2
<b>C</b>	19:42:38.269	−10:17:46.90	16.71 (0.06) 1	15.98 (0.03) 2	14.90 (0.02) 3	14.40 (0.03) 3	13.91 (0.04) 2
<b>D</b>	19:42:47.459	−10:17:42.35	18.06 (0.08) 1	17.42 (0.03) 2	16.38 (0.02) 3	15.88 (0.03) 3	15.41 (0.05) 2
<b>E</b>	19:42:45.795	−10:17:40.85	17.81 (0.07) 1	16.33 (0.03) 2	14.93 (0.03) 3	14.28 (0.03) 3	13.68 (0.05) 2
<b>F</b>	19:42:36.006	−10:17:22.74	17.52 (0.07) 1	16.92 (0.03) 2	15.93 (0.02) 3	15.45 (0.03) 3	15.01 (0.05) 2
<b>Mrk 304</b>							
<b>A</b>	22:17:17.819	14:13:28.11	15.69 (0.06) 1	15.42 (0.04) 2	14.65 (0.03) 2	14.23 (0.04) 2	13.84 (0.06) 2
<b>B</b>	22:17:04.362	14:14:37.28	17.86 (0.06) 1	17.82 (0.04) 2	17.09 (0.03) 2	16.68 (0.04) 2	16.31 (0.06) 2
<b>C</b>	22:17:14.323	14:15:08.79	17.58 (0.05) 1	17.66 (0.04) 2	16.98 (0.03) 2	16.55 (0.04) 2	16.15 (0.06) 2
<b>D</b>	22:17:08.602	14:15:25.62	19.32 (0.05) 1	18.03 (0.04) 2	16.85 (0.03) 2	16.16 (0.04) 2	15.59 (0.06) 2
<b>E</b>	22:17:05.070	14:15:29.10	17.02 (0.06) 1	16.31 (0.04) 2	15.33 (0.03) 2	14.78 (0.04) 2	14.27 (0.06) 2
<b>F</b>	22:17:20.088	14:15:43.74	18.47 (0.07) 1	18.32 (0.05) 2	17.59 (0.03) 2	17.11 (0.05) 2	16.70 (0.07) 2
<b>G</b>	22:17:19.755	14:16:06.40	17.44 (0.07) 1	17.38 (0.05) 2	16.65 (0.03) 2	16.21 (0.05) 2	15.81 (0.07) 2

**Table 2** Continued.

Star	RA (J2000)	Dec (J2000)	$U$	$B$	$V$	$R_C$	$I_C$
<b>Ark 564</b>							
<b>A:</b> 3 <sup>d</sup>	22:42:39.265	29:44:21.03	14.16 (0.09) 2	14.17 (0.07) 2	13.58 (0.05) 2	13.27 (0.07) 2	12.97 (0.06) 2
<b>B:</b> 1 <sup>f</sup>	22:42:48.379	29:45:22.30	13.90 (0.13) 2	13.97 (0.09) 2	13.44 (0.07) 2	13.17 (0.09) 2	12.93 (0.08) 2
<b>C:</b> 2 <sup>d</sup> , 13 <sup>f</sup>	22:42:32.084	29:45:27.02	15.85 (0.11) 2	15.77 (0.08) 2	15.07 (0.07) 2	14.74 (0.08) 2	14.43 (0.08) 2
<b>D:</b> 1 <sup>d</sup> , 12 <sup>f</sup>	22:42:35.122	29:45:37.96	15.56 (0.09) 2	15.42 (0.08) 2	14.73 (0.07) 2	14.41 (0.09) 2	14.12 (0.08) 2
<b>NGC 7469</b>							
<b>A</b>	23:03:10.785	08:50:43.14	18.59 (0.17) 2	18.81 (0.05) 2	18.20 (0.04) 2	17.93 (0.04) 2	17.55 (0.06) 2
<b>B</b>	23:03:07.717	08:51:43.43	17.22 (0.10) 2	17.38 (0.05) 2	16.73 (0.05) 2	16.43 (0.04) 2	16.02 (0.06) 2
<b>C</b>	23:03:12.216	08:52:12.93	17.46 (0.10) 2	17.65 (0.04) 2	17.06 (0.04) 2	16.75 (0.04) 2	16.32 (0.05) 2
<b>D</b>	23:03:23.233	08:53:21.83	18.34 (0.13) 2	18.62 (0.06) 2	17.96 (0.05) 2	17.67 (0.04) 2	17.29 (0.06) 2

<sup>a</sup> Penston et al. (1971), <sup>b</sup> Curry et al. (1998), <sup>c</sup> Bachev et al. (2000), <sup>d</sup> Shemmer et al. (2001), <sup>e, f</sup> Doroshenko et al. (2005a, 2005b).

dividual frames of each object in a given passband were aligned using `ALIGN/IMAGE` and `REBIN/ROTATE` commands and then averaged.

### 3 Flux measurement and calibration

The flux measurements of all objects of interest were performed using `DAOPHOT` package run within `ESO-MIDAS` (Stetson 1987). The growth curve technique was used to obtain the total instrumental magnitudes ensuring good accuracy even for weak stars (Stetson 1990); we found no variations of PSF across the CCD camera field and, therefore, the usage of this technique is justified<sup>1</sup>. Neighbourhood objects to the stars used to build the mean growth curve of a given frame were cleaned out using either the technique presented by Markov et al. (1997) or the star subtraction technique based on `DAOPHOT`. We were not able to derive accurate aperture corrections for the  $U$  band frames of 3C 382 and NGC 7469 due to the lack of stars with high enough signal-to-noise ratio in our frames. We measured the stars of interest directly in an aperture of  $5 \times \text{FWHM}$  radius in these cases (usually at this radius the growth curve asymptotically flattens). The sky background level was estimated as the mode of the pixel values in an annulus having an inner radius of  $7 \times \text{FWHM}$  pixels and an outer radius of  $[1000/\pi + (7 \times \text{FWHM})^2]^{0.5}$  pixels; the outer radius was chosen so that the annulus should contain a total of about 1000 pixels. This choice was made to ensure a constant number of sky pixels independently on the seeing conditions; otherwise, the accuracy of the mean local sky background determination would vary depending on the number of pixels in the sky annulus (the error of the mean over  $N$  pixels is  $N^{0.5}$  times smaller than the error of the single pixel). Therefore, the uncertainty in flux measurements due to the uncertainty of the sky level would get larger as the number of sky pixels decreases.

<sup>1</sup> The growth curve magnitudes of a number of comparison stars were found to be identical with the single,  $5 \times \text{FWHM}$  radius aperture magnitudes to within the measurement errors. This is another confirmation of the growth curve technique applicability in our measurements.

A second-order polynomial correction for the presence of scattered light<sup>2</sup> in the telescope was applied according to

$$m_{\text{obs}} - m_{\text{corr}} = p(d/512.5) + q(d/512.5)^2,$$

where  $m_{\text{obs}}$  and  $m_{\text{corr}}$  are the observed and corrected instrumental magnitudes, respectively,  $p$  and  $q$  are the polynomial coefficients, and  $d$  is the distance to the frame centre. The cluster standards observed during the period 1997 – 1999 were used to calculate the mean polynomial coefficients of the correction.

The transformation of the total instrumental magnitudes to the standard system was done following Harris, Fitzgerald & Reed (1981) methodology. It assumes determination of the extinction and photometric transformation coefficients at once; the imaging of multi-star standard fields ensures the accurate determination of the extinction coefficients even with two or three standard observations during the night. The transformation equations read:

$$\begin{aligned} u - U &= c_U^{(0)} + c_U^{(1)} X + c_U^{(2)} (U - B) \\ b - B &= c_B^{(0)} + c_B^{(1)} X + c_B^{(2)} (B - V) \\ v - V &= c_V^{(0)} + c_V^{(1)} X + c_V^{(2)} (V - R) \\ r - R &= c_R^{(0)} + c_R^{(1)} X + c_R^{(2)} (V - R) \\ i - I &= c_I^{(0)} + c_I^{(1)} X + c_I^{(2)} (R - I), \end{aligned}$$

where the small and the capital letters denote the instrumental and the catalogue magnitudes of the cluster standard stars, respectively;  $X$  is the airmass,  $c^{(0)}$  is the zero-point magnitude,  $c^{(1)}$  is the extinction coefficient, and  $c^{(2)}$  is the colour coefficient. The transformation coefficients,  $c$ , and their errors were determined solving the linear set of equations  $\partial\chi^2(c)/\partial c = 0$  for the total instrumental and

<sup>2</sup> Scattered light affects both the science and the flat field frames in the same manner. Being added to the flat field frame, it will take part in a multiplicative way in the flat field correction; as a result the sky background will be flat but the photometry will be dependent on the object position on the CCD chip (see Manfroid, Selman & Jones 2001; Boyle et al. 2003). The presence of scattered light in the 2-m telescope of NAO was detected through camera obscura experiments (H. Markov, private communication; see also Grundahl & Sørensen 1996).

catalogue magnitudes of the cluster standards employing Gauss-Jordan algorithm; the weights applied were equal to the inverse sum of the square errors of the instrumental and catalogue magnitudes. The transformation equations were applied to the night data, so, the transformation coefficients were determined for each observing night.

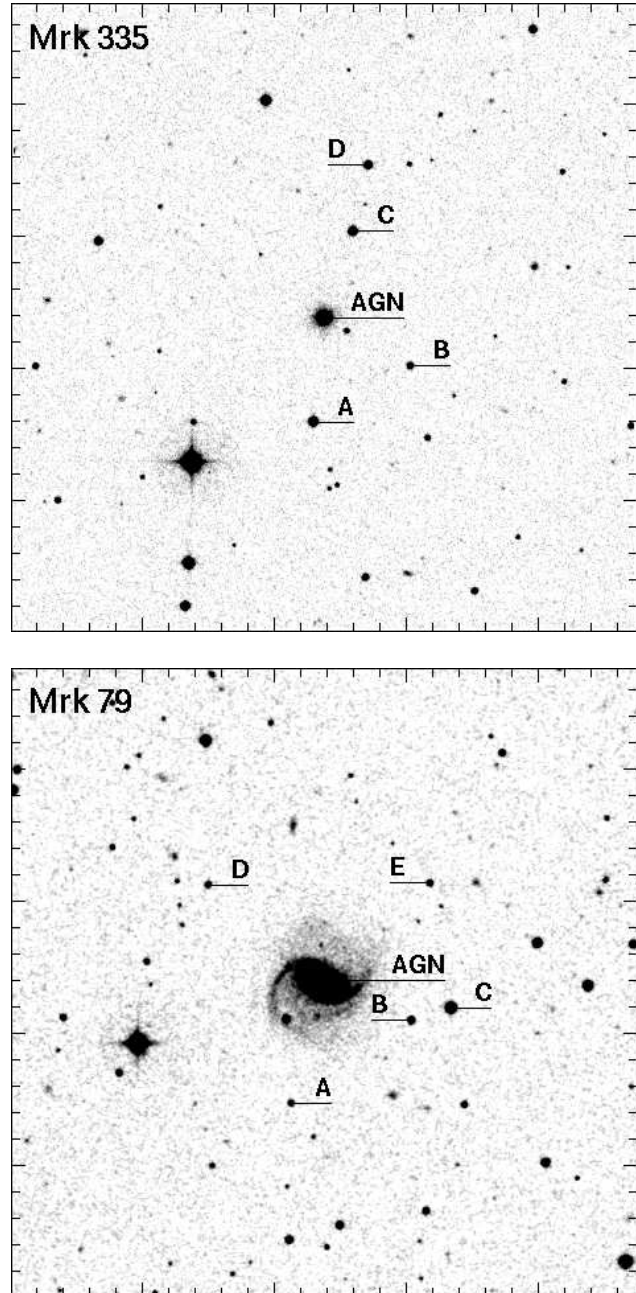
The total instrumental magnitudes of the comparison stars were transformed to the standard Johnson-Cousins system inverting the above equations with the transformation coefficients substituted. The uncertainties of the magnitudes were estimated by means of the standard error propagation rules taking into account the errors of the instrumental magnitudes as returned by DAOPHOT, the errors of the scattered light polynomial correction coefficients, and the errors of the transformation coefficients. In all cases of multi-epoch observations the calibrated magnitudes were weight-averaged; the errors of the mean magnitudes were calculated taking the larger between (1) the error estimate based on the individual magnitude errors and (2) the error estimate based on the scatter of magnitudes involved in averaging about their weight-mean value (see Stetson, Bruntt & Grundahl 2003).

The calibrated apparent magnitudes of the comparison stars are presented in Table 2; the equatorial coordinates have been obtained using ALADIN web facility (Bonnarel et al. 2000). The comparison stars are denoted with capital letters in order of increasing declination. We list the other designations of the stars having literature calibrations as well as the corresponding papers in Table 2 in order to facilitate the cross-identifications of the comparison stars. The finding charts are presented in Fig. 1; they have been prepared using digitized *B* or *R* plates (depending on the quality) of the Second Palomar Observatory Sky Survey (POSS-II).

#### 4 General characteristics of the comparison stars

The calibrated comparison stars cover *V* band flux range from 11.7 to 18.2 mag with a median value of 16.3 mag and *B* – *V* colour index range from 0.4 to 1.6 mag with a median value of 0.8 mag. The colour index range roughly corresponds to a spectral type interval from F to M for main sequence stars. The lack of blue stars among the standards is obvious – this could be considered as a disadvantage of the presented comparison stars since Seyfert nuclei are blue objects.

The minimal, median, and maximal magnitude errors of the calibrated comparison stars in respective order are the following: *U* band – 0.04, 0.08, and 0.21 mag; *B* band – 0.03, 0.04, and 0.09 mag; *V* band – 0.02, 0.03, and 0.08 mag; *R<sub>C</sub>* band – 0.02, 0.04, and 0.09 mag; *I<sub>C</sub>* band – 0.04, 0.06, and 0.11 mag. The largest errors are attributed to the *U* band magnitudes (due to the lower sensitivity of the CCD chip) and to the *I<sub>C</sub>* band ones (due to the high sky background level and due to the presence of a fringe pattern).



**Fig. 1** Finding charts for the comparison stars. The size of the charts is  $8 \times 8$  arcmin and the distance between the ticks is 20 arcsec. North is at the top, East is to the left.

We did several checks of the accuracy of our calibration and for the eventual presence of variable stars in the calibrated comparison sequences.

Firstly, all comparison stars were queried in SIMBAD astronomical database for eventual coincidence with known variable stars. The results were negative for a search radius of 30 arcsec around the star positions.

Secondly, an internal check for variability was done for the stars calibrated for the first time. This was done by means of a multiband differential photometry of the comparison

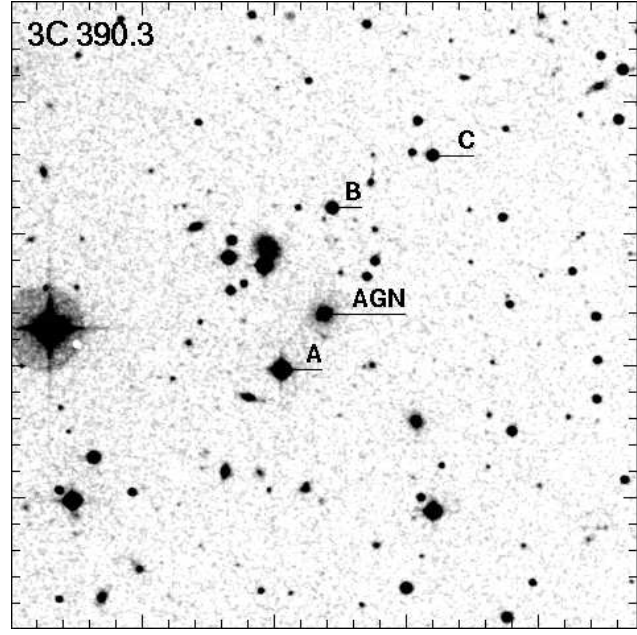
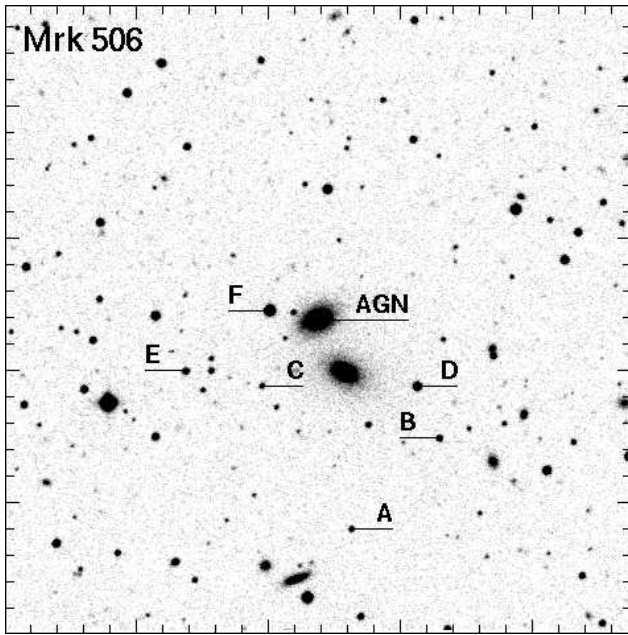
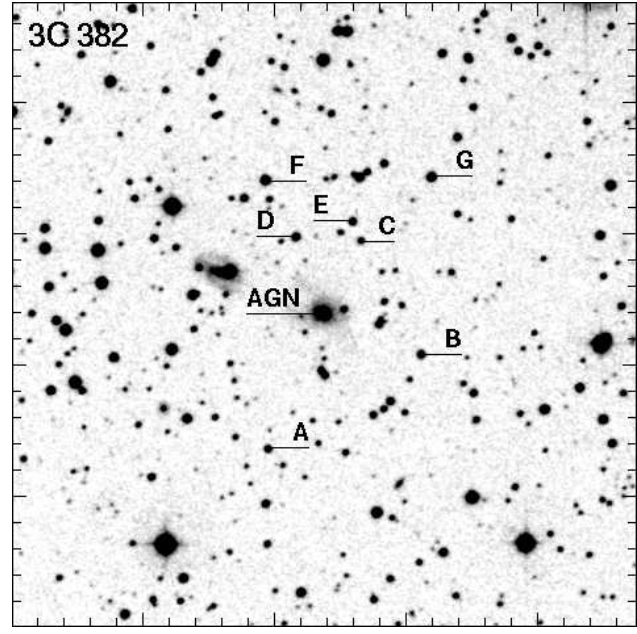
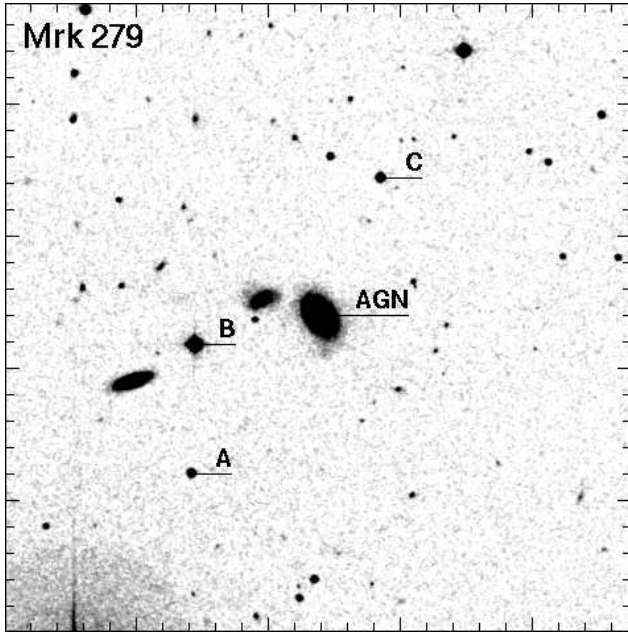


Fig. 1 Continued.

Fig. 1 Continued.

stars relative to the brightest one in the corresponding field. We complemented the photometric night data with data from non-calibrated nights (see Sect. 1) and with data obtained during 2007 June observing run<sup>3</sup> in order to increase the significance of the internal check; the number of nights used

<sup>3</sup> We observed Mrk 506, 3C 382, and Mrk 304 fields with the 2-m telescope of NAO in a single night during this run. These fields were imaged through Johnson-Cousins  $BVR_CI_C$  filters using  $1340 \times 1300$  Princeton Instruments VersArray:1300B model CCD camera that has EEV (Marconi) CCD36-40 chip with  $20 \mu\text{m}$  square pixel ( $0.258 \text{ arcsec px}^{-1}$  scale factor). Observations and data reduction were performed in a manner similar to that described in Sect. 2. No calibration was performed due to the unstable weather conditions.

in the internal check for variability of the newly calibrated comparison stars is specified in Table 1. We found the mean absolute deviation about the median instrumental magnitude difference to be compatible with or less than the median error of the calibrated magnitudes for each passband and star light curve. A few exceptions were found that could be attributed to single bad measurements rather than to variability. Note that an eventual large difference between the individual magnitude estimates will result – after the weight-averaging – in a large error in the final magnitude. Based on the above considerations we could conclude that the comparison stars calibrated for the first time could be assumed



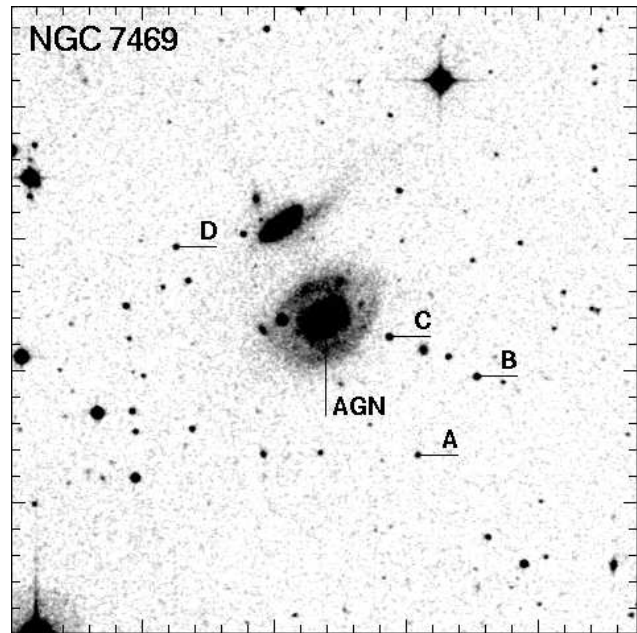
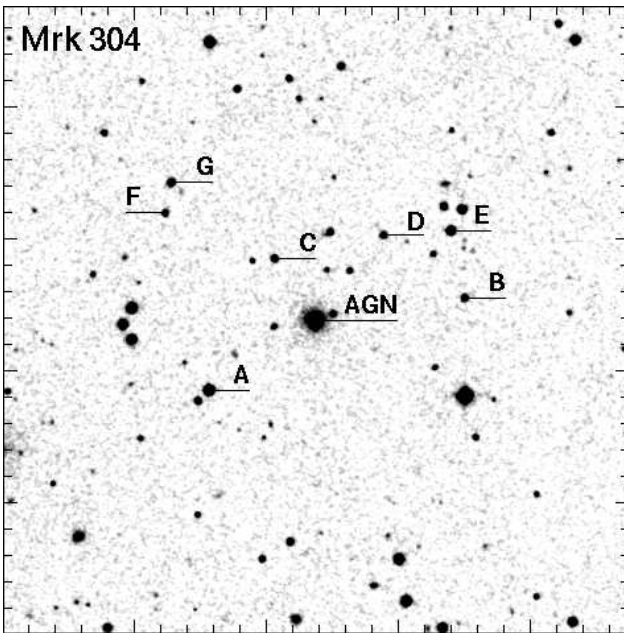
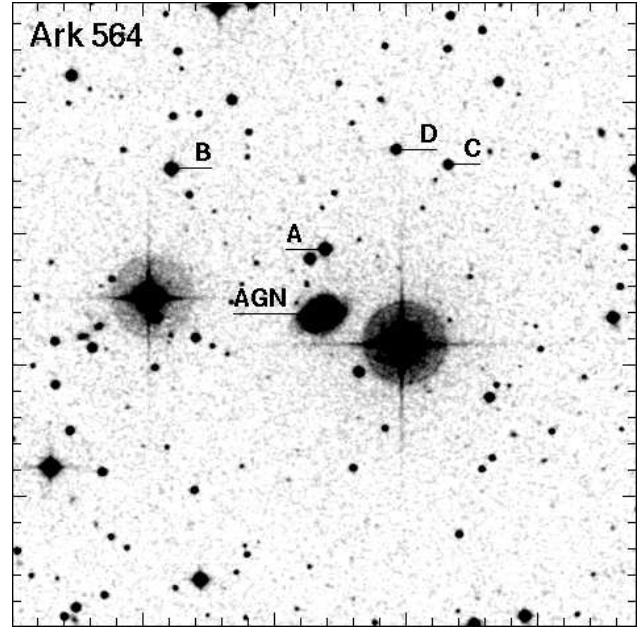
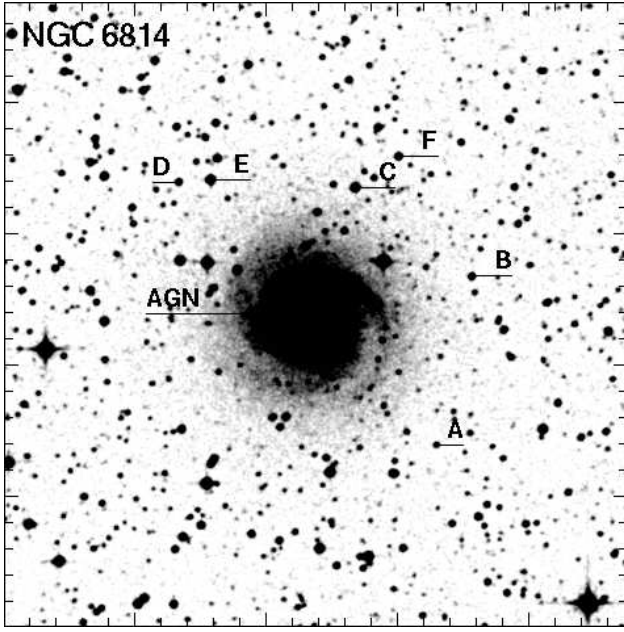


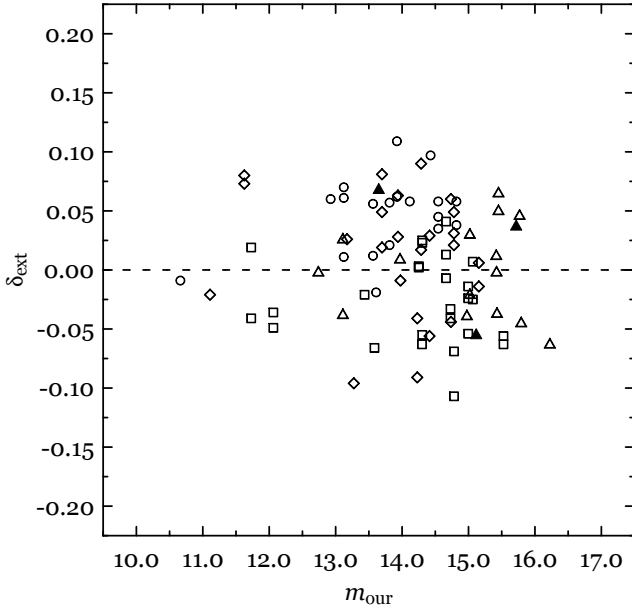
Fig. 1 Continued.

Fig. 1 Continued.

to be non-variable down to amplitudes compatible with the uncertainties of their calibrated magnitudes.

And finally, we considered an external check of our calibration in the cases when literature results were found; note that *Ic1* and *Ic2* magnitudes published by Doroshenko et al. (2005a, 2005b) were weight-averaged before their usage in the external check. In Fig. 2 the differences between our magnitudes and the magnitudes calibrated by other authors,  $\delta_{\text{ext}} = m_{\text{our}} - m_{\text{other}}$ , are plotted against our magnitudes,  $m_{\text{our}}$ , listed in Table 2. In Fig. 3 we plot  $\delta_{\text{ext}}$  against the  $V - R_C$  colour index of the comparison stars. We found the median value of the quantity  $|\delta_{\text{ext}}|/(\sigma_{\text{our}}^2 + \sigma_{\text{other}}^2)^{0.5}$

(where  $\sigma_{\text{our}}$  and  $\sigma_{\text{other}}$  are the errors of our magnitudes and of the literature ones, respectively) to be less than unity for all passbands. These considerations suggest that there are no significant systematic deviations of our calibration from the previously published results depending on the passband, colour index or magnitude. So, we could conclude that the differences between our magnitudes and the literature ones are caused by measurement and calibration uncertainties and, therefore, our calibrations agree with the literature ones to within the errors. This could also be considered as evidence for non-variability of the re-calibrated stars compared to



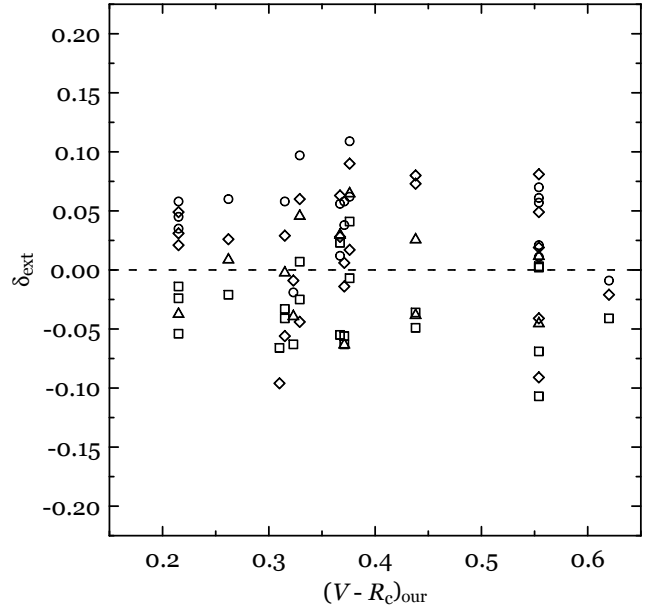
**Fig. 2** An external check of our calibration: the values of  $\delta_{\text{ext}}$  are plotted against  $m_{\text{our}}$ . Different passbands are marked as follows:  $U$  – filled triangles,  $B$  – open triangles,  $V$  – squares,  $R_C$  – diamonds, and  $I_C$  – circles. Individual objects are not specified for the sake of clarity.

their previous calibrations down to amplitudes compatible with the magnitude errors.

## 5 Comments on the individual fields

*Mrk 335.* Calibrations of stars in this field were done by Curry et al. (1998) – three stars in the  $VR_CI_C$  bands, Bachev et al. (2000) – four stars in the  $VR_CI_C$  bands, and Doroshenko et al. (2005a) – seven stars in the  $BVR_CI_C$  bands. There are two stars calibrated by us, A and C, that have been measured by the above authors as well; our calibration confirms the literature results to within the errors. We added two new comparison stars, thus extending the sequence to fainter magnitudes compared to the previous calibrations – our star B is the faintest one calibrated in this field so far. We calibrated  $U$  band magnitudes of stars in this field for the first time.

*Mrk 79.* Calibration of stars in this field was done by Doroshenko et al. (2005a) – six stars in the  $BVR_CI_C$  bands. We have only one common star with them – our star C is their star 4. The other stars calibrated by Doroshenko et al. (2005a) are outside our field of view. We added four new comparison stars that are closer to the galaxy and fainter than the stars previously calibrated. We also calibrated  $U$  band magnitudes of stars in this field for the first time. The magnitudes of star C are single epoch ones because the star was outside our field of view at the second epoch. This field was also included in the paper of Curry et al. (1998), but no calibrated magnitudes were reported by them.



**Fig. 3** An external check of our calibration: the values of  $\delta_{\text{ext}}$  are plotted against  $(V - R_C)_{\text{our}}$ . Different passbands are marked as in Fig. 2.

*Mrk 279.* Calibrations of stars in this field were done by Bachev et al. (2000) – four stars in the  $VR_CI_C$  bands<sup>4</sup>, and Doroshenko et al. (2005b) – four stars in the  $BVR_CI_C$  bands. We were not able to add new comparison stars, but confirmed the previous calibrations of some of the stars (see Table 2) to within the errors and extended the passband coverage of the calibrated magnitudes towards the  $U$  band. We were not able to calibrate star B in the  $R_CI_C$  bands because it was saturated in the corresponding frames.

*Mrk 506.* No other  $UBVR_CI_C$  calibrations of this field exist to our knowledge.

*3C 382.* No other  $UBVR_CI_C$  calibrations of this field exist to our knowledge. The second epoch  $B$  band frames of this field were of low quality due to scattered light and the corresponding magnitudes were discarded because they showed large differences compared to the first epoch measurements, i.e. no weight-averaging was performed in this case.

*3C 390.3.* Calibrations of stars in this field were done by Penston et al. (1971) – three stars in the  $UBV$  bands, Curry et al. (1998) – three stars in the  $VR_CI_C$  bands, and Doroshenko et al. (2005b) – eleven stars in the  $BVR_CI_C$  bands. We re-calibrated some of the stars (see Table 2) measured by the above authors confirming their results to within the errors over all passbands. We were not able to obtain two-epoch data for star A in the  $R_CI_C$  bands because it was saturated in the corresponding second epoch frames.

*NGC 6814.* Calibration of stars in this field was done by Doroshenko et al. (2005b) – six stars in the  $BVR_CI_C$  bands. We have no common stars with them because their

<sup>4</sup> The  $B$  band magnitude of star A of Bachev et al. (2000) is presented in Bachev & Strigachev (2004).



stars 3, 6, 8, and 9 are outside our field of view, whereas stars 1 and 2 are saturated in our frames. We added six new stars to the field of the object, fainter than previously calibrated standards;  $U$  band magnitudes were also calibrated by us. Star A was not detected in our  $U$  band frames, so, we could not obtain  $U$  band magnitude for it. We excluded the second epoch  $B$  magnitudes and the first epoch  $I_C$  ones from weight-averaging due to the large differences compared to the other epoch measurements.

*Mrk 304.* No other  $UBVR_CI_C$  calibrations of this field exist to our knowledge.

*Ark 564.* Calibrations of stars in this field were done by Shemmer et al. (2001) – three stars in the  $BVR_CI_C$  bands, and Doroshenko et al. (2005b) – twelve stars in the  $BVR_CI_C$  bands. We did not add new comparison stars to this field, but we re-calibrated some of the stars (see Table 2) measured by the above authors and added  $U$  band magnitudes. We confirmed the literature results to within the errors with the following exception: we found the  $BI_C$  magnitude differences for our stars A, C, and D compared to stars 1, 2, and 3 of Shemmer et al. (2001) in the field of Ark 564 to be  $\delta_{\text{ext}} \approx -0.6$  mag; differences of the same order were found by Doroshenko et al. (2005b). On the other hand, our  $VR_C$  magnitudes are in good agreement with both sets of literature results. Therefore, there is some kind of error or misprint concerning the  $BI_C$  magnitudes of stars 1, 2, and 3 presented by Shemmer et al. (2001). The magnitude differences corresponding to these deviated magnitudes were not plotted in Fig. 2 and in Fig. 3. Doroshenko et al. (2005b) claimed that their star 12 may be a low-amplitude variable (see Table 2 for the other designations of this star). We cannot confirm or reject this finding because our magnitude errors are larger than the variability amplitudes estimated by Doroshenko et al. (2005b).

*NGC 7469.* Calibrations of stars in this field were done by Penston et al. (1971) – five stars in the  $UBV$  bands, and Doroshenko et al. (2005b) – nine stars in the  $BVR_CI_C$  bands. We have no common stars with both groups because their stars are outside our field of view. We added four new stars to the field of the object, closer to the galaxy and fainter than previously calibrated standards.

## 6 Summary

We have calibrated Johnson-Cousins  $UBVR_CI_C$  magnitudes of 49 stars in the fields of the Seyfert galaxies Mrk 335, Mrk 79, Mrk 279, Mrk 506, 3C 382, 3C 390.3, NGC 6814, Mrk 304, Ark 564, and NGC 7469 in order to facilitate photometric monitoring of these objects; 36 stars have been measured for the first time. Our magnitudes are in good agreement with the published ones and we have found no signs of variability of the calibrated comparison stars at least with amplitudes down to the estimated magnitude errors.

We have calibrated in Johnson-Cousins  $UBVR_CI_C$  system the comparison stars in three of the fields, Mrk 506, 3C 382, and Mrk 304, for the first time (to our knowledge)

and we have improved the existing standard sequences in the other fields. New comparison stars have been added to the fields of Mrk 335 (two stars), Mrk 79 (four stars), NGC 6814 (six stars), and NGC 7469 (four stars) – most of the newly added stars are fainter and are situated closer to the Seyfert galaxies compared to the existing standards. The passband coverage of the comparison sequences in the fields of Mrk 335, Mrk 79, Mrk 279, NGC 6814, and Ark 564 have been complemented with the  $U$  band.

Future observations of the presented comparison sequences are welcome in order to improve them further.

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This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

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